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THE TEMPERATURE COEFFICIENT OF THE DURATION OF LIFE OF BARLEY GRAINS

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LOEB[1] believes that the chemical reactions underlying the development of organisms differ widely from those that bring about natural death. This author has found, for sea urchin eggs, the temperature coefficient of duration of life to lie between 500 and 1000 for a rise of temperature of 10° C., while that of development was 2.86 for a similar temperature interval. This latter figure is identical with that previously calculated by PETER[2] from the results obtained by HERTWIG[3] in experiments upon the effect of temperature on the rate of development of frogs' eggs. MOORE,[4] using *Tubularia crocea*, states that the temperature coefficient of life duration in this hydroid was about 1000 for a rise of temperature of 10° C., and that the average temperature coefficient for the process of regeneration was 3.4 for a 10° C. interval. The influence of temperature upon the development of plants has been given some attention; but the results, as given in the literature, with a few exceptions yield no accurate conclusions. The obvious effect upon reaction velocities of even slight variations in the temperature, when the whole temperature range employed lies well within that which is normal for the subjects investigated, is the cause assigned for the inaccuracy of the results obtained. However, the careful experiments of CLAUSEN[5] upon the influence of temperature on the excretion of carbon dioxide by bean germs, wheat germs, and syringa buds have been widely recognized, and set a criterion of accuracy and technic for the investigations of plant physiologists along these general lines.

It was suggested to me that a temperature coefficient for the duration of life of seeds might yield interesting results if the determinations could be made sufficiently accurate. Experiments were accordingly begun September 1, 1910, and continued for some three months. It seemed to me that the use of barley in such an experiment would possibly yield results of the most scientific interest, since, from the observations of KIRCHHOFF[6] to the comprehensive researches of BROWN and MORRIS[7] and others, this member of the Gramineae has been the subject of much investigation.

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[1] LOEB, JACQUES, Archiv. Ges. Physiol. **124**:411.

[2] PETER, KARL, Archiv. Entw.-Mech. **20**:130.

[3] HERTWIG, O., Archiv. Mikr. Anat. u. Entw.-Gesch. **51**:893.

[4] MOORE, A. R., Archiv. Entw.-Mech. **29**:145, 287.

[5] CLAUSEN, Landwirtschaftliche Jahrbücher **19**:893.

The material was obtained from the American Hop and Barley Company, grown at their ranches in Butte County, California, and harvested during August 1910. The grain was given no specific name by the company, but is known in the trade as malt or brewing barley. Through the courtesy of the company, a quantity of their best grain used for exhibition purposes was at my disposal. It was characterized by them as being a trifle under the maximum weight, but uniform throughout and of the best color.

Previous to every temperature determination, the inferior palea of each barley grain was carefully removed, and 50 seeds were soaked in tap water for one hour. The material thus prepared was used within ten minutes after being removed from the water. It was judged that the removal of the outer seed coat would obviate the source of error that might otherwise be introduced through the different degrees of resistance to penetration offered by the protective coverings. By soaking previous to the experiments it was hoped that sufficient water would enter the tissues of the grain to affect a more rapid adjustment of the temperatures within and without the seed when placed in the water bath. The use of more than 50 seeds for each determination was considered to be unnecessary, inasmuch as control experiments including over 2000 seeds gave only 0.4 per cent as the percentage that would not germinate under normal conditions. This source of error may be considered negligible.

Two methods were employed for maintaining a constant temperature. In the first a double water bath heated by a Bunsen burner flame was used, the regulation of the temperature being made automatic by the use of a mercury thermo-regulator. A finger bowl containing 100 cc. of tap water stood upon the water bath, and the seeds, lying upon a square of loosely woven cotton cloth, were placed within it. By the use of such a container for the seeds, it was possible to remove all of the material at exactly the same moment. In the second method an electric incubator, within which stood a beaker containing 100 cc. of water, was found to give excellent results. An additional stove attachment and an electric regulator on the apparatus made it possible to maintain high and constant temperatures. When the temperature in the beaker had been kept constant at the desired point for an hour, the seeds were dropped into the water and could be taken out at the end of the time intervals almost as rapidly as in the former method. The whole temperature range given in the table below was covered according to the second method, while the effect of temperatures between 60° and 70° C. was investigated according to the first. The variations in temperature amounted to 0°2 C. for the temperatures above 60° C., and 0°3 C. for all temperatures below and including 60° C. The time during which these variations lasted, however, was relatively so short that this source of error may be disregarded.

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[6] KIRCHHOFF, SCHWEIG'S Journal **14**:389. 1815.

[7] BROWN and MORRIS, Jour. Chem. Soc. **57**:458.

For observing the progress of germination the seeds were placed upon moist filter paper so arranged in a finger bowl containing about 20 cc. of water that the surface of the paper was continually moist without any appreciable amount of water surrounding the seeds. In many cases the paper was perforated and the seeds, proximal end downward, were lightly pushed into the openings. A difficulty was encountered in connection with the molds *Rhizopus nigricans* and *Penicillium crustaceum*, which usually attacked the seeds on the third or fourth day. Any seeds that were evidently dead and decomposing were at once discarded as soon as the mold appeared, and any others affected but showing signs of germination were carefully watched and kept free from mold by wiping with sterilized lens paper. In all cases the material was kept at room temperature and in partial darkness.

The criterion of complete development was the appearance of the green shoot above the plumule sheath or the formation of roots from the swollen radical extremity. The normal stages observed in the germination of barley are, first, the protrusion of the calyptrogen and a rapid development of the three primary roots therefrom, and second, the appearance, at a shortly later period, of the plumule sheath, within which the leaves of the plumule are contained. The effect of all temperatures above 64°C. for the time intervals mentioned below was to inhibit in every case the normal development of the radicle. Development appeared in the plumule after intervals varying from 15 to 30 hours, and continued slowly until at the end of two days the green shoot began to show. From 2 to 3 days later adventitious roots began to take form from the basal portion of the plumule sheath, probably from the point of origin of the procambium strands that enter the scutellum, leaves, and radicle. The germination and subsequent development of certain seeds subjected to a temperature of 66° C. for 5 minutes was observed through a period of five weeks, and it was noted that after the appearance of the adventitious roots growth proceeded rapidly, and at the end of this period these plants compared favorably with those germinating normally and growing for an equal length of time.

Temperature Centigrade	Duration of life	Temperature coefficient for 1° C.
70	1½–2	
69	2– 2¾	1.3
68	3– 5	1.7
67	4– 5	1.1
66	5– 6	1.2
65	6– 8	1.3
64	7– 9	1.1
63	10–12	1.4
62	11–12	1.0
61	15–16	1.3
60	18–19	1.2
59	21–24	1.2
58	24–26	1.1
57	32–35	1.3
56	42–47	1.3
55	65–70	1.5
Average temp. coefficient 1.27		

The preceding table expresses the results of some 300 separate determinations in which over 15,000 seeds were used. Each time interval was repeatedly verified, and since in some cases exactly corresponding results could not be obtained, an average was in such cases taken. The duration of life of the seeds was taken to be the time in minutes for which a given temperature must act in order to inhibit the subsequent growth of all the seeds when placed under the conditions above described.

The temperature coefficient of the duration of life of barley grains has been determined for the temperatures 55°–70° C., inclusive, and has been found to be about 11 for a temperature interval of 10°. This is of the order of magnitude demanded by the law of VAN'T HOFF and ARRHENIUS for the temperature coefficient of a chemical reaction, but is much less than the temperature coefficient of duration of life of sea urchin eggs as determined by LOEB.

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